AP® CHEMISTRY
2010 SCORING GUIDELINES

Question 1
(10 points)

Several reactions are carried out using AgBr, a cream-colored silver salt for which the value of the solubility-product-constant, K_{sp}, is 5.0×10^{-13} at 298 K.

(a) Write the expression for the solubility-product constant, K_{sp}, of AgBr.

$K_{sp} = [Ag^+][Br^-]$	One point is earned for the correct expression (ion charges must be present; parentheses instead of square brackets not accepted).

(b) Calculate the value of $[Ag^+]$ in 50.0 mL of a saturated solution of AgBr at 298 K.

Let x = equilibrium concentration of Ag^+ (and of Br^-). Then $K_{sp} = 5.0 \times 10^{-13} = x^2 \Rightarrow x = 7.1 \times 10^{-7}\ M$	One point is earned for the correct value with supporting work (units not necessary).

(c) A 50.0 mL sample of distilled water is added to the solution described in part (b), which is in a beaker with some solid AgBr at the bottom. The solution is stirred and equilibrium is reestablished. Some solid AgBr remains in the beaker. Is the value of $[Ag^+]$ greater than, less than, or equal to the value you calculated in part (b) ? Justify your answer.

The value of $[Ag^+]$ after addition of distilled water is equal to the value in part (b). The concentration of ions in solution in equilibrium with a solid does <u>not</u> depend on the volume of the solution.	One point is earned for the correct answer with justification.

(d) Calculate the minimum volume of distilled water, in liters, necessary to completely dissolve a 5.0 g sample of AgBr(*s*) at 298 K. (The molar mass of AgBr is 188 g mol^{-1}.)

$5.0\text{ g AgBr} \times \frac{1\text{ mol AgBr}}{188\text{ g AgBr}} = 0.0266\text{ mol AgBr}$ $\frac{0.0266\text{ mol}}{\text{V}} = 7.1 \times 10^{-7}\text{mol L}^{-1} \Rightarrow \text{V} = 3.7 \times 10^{4}\text{ L}$	One point is earned for the calculation of moles of dissolved AgBr. One point is earned for the correct answer for the volume of water

Question 1 (continued)

(e) A student mixes 10.0 mL of $1.5 \times 10^{-4}\ M$ $AgNO_3$ with 2.0 mL of $5.0 \times 10^{-4}\ M$ NaBr and stirs the resulting mixture. What will the student observe? Justify your answer with calculations.

$[Ag^+] = \frac{(10.0\text{ mL})(1.5 \times 10^{-4}\ M)}{12.0\text{ mL}} = 1.3 \times 10^{-4}\ M$ $[Br^-] = \frac{(2.0\text{ mL})(5.0 \times 10^{-4} M)}{12.0\text{ mL}} = 8.3 \times 10^{-5}\ M$ $Q = [Ag^+][Br^-] = (1.3 \times 10^{-4}\ M)(8.3 \times 10^{-5}\ M) = 1.1 \times 10^{-8}$ $1.1 \times 10^{-8} > 5.0 \times 10^{-13}$, $\therefore$ a precipitate will form.	One point is earned for calculation of concentration of ions. One point is earned for calculation of Q and conclusion based on comparison between Q and K_{sp}. One point is earned for indicating the precipitation of AgBr.

(f) The color of another salt of silver, AgI(*s*), is yellow. A student adds a solution of NaI to a test tube containing a small amount of solid, cream-colored AgBr. After stirring the contents of the test tube, the student observes that the solid in the test tube changes color from cream to yellow.

(i) Write the chemical equation for the reaction that occurred in the test tube.

$AgBr(s) + I^-(aq) \rightarrow AgI(s) + Br^-(aq)$ ***OR*** $AgBr(s) + NaI(aq) \rightarrow AgI(s) + NaBr(aq)$	One point is earned for the correct equation.

(ii) Which salt has the greater value of K_{sp}: AgBr or AgI ? Justify your answer.

AgBr has the greater value of K_{sp}. The precipitate will consist of the less soluble salt when both $I^-(aq)$ and $Br^-(aq)$ are present. Because the color of the precipitate in the test tube turns yellow, it must be AgI(*s*) that precipitates; therefore K_{sp} for AgBr must be greater than K_{sp} for AgI. ***OR*** K_{eq} for the displacement reaction is $\frac{K_{sp}\text{ of AgBr}}{K_{sp}\text{ of AgI}}$. Because yellow AgI forms, $K_{eq} > 1$; therefore K_{sp} of AgBr > K_{sp} of AgI.	One point is earned for the correct choice with justification.

1A,

CHEMISTRY

Section II

Total time—95 minutes)

Part A

Time—55 minutes

YOU MAY USE YOUR CALCULATOR FOR PART A.

CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures.

Be sure to write all your answers to the questions on the lined pages following each question in the booklet with the pink cover. Do NOT write your answers on the green insert.

Answer Questions 1, 2, and 3. The Section II score weighting for each question is 20 percent.

1. Several reactions are carried out using AgBr, a cream-colored silver salt for which the value of the solubility-product constant, K_{sp}, is 5.0×10^{-13} at 298 K.

   (a) Write the expression for the solubility-product constant, K_{sp}, of AgBr.

   (b) Calculate the value of $[Ag^+]$ in 50.0 mL of a saturated solution of AgBr at 298 K.

   (c) A 50.0 mL sample of distilled water is added to the solution described in part (b), which is in a beaker with some solid AgBr at the bottom. The solution is stirred and equilibrium is reestablished. Some solid AgBr remains in the beaker. Is the value of $[Ag^+]$ greater than, less than, or equal to the value you calculated in part (b) ? Justify your answer.

   (d) Calculate the minimum volume of distilled water, in liters, necessary to completely dissolve a 5.0 g sample of AgBr(*s*) at 298 K. (The molar mass of AgBr is 188 g mol^{-1}.)

   (e) A student mixes 10.0 mL of 1.5×10^{-4} *M* $AgNO_3$ with 2.0 mL of 5.0×10^{-4} *M* NaBr and stirs the resulting mixture. What will the student observe? Justify your answer with calculations.

   (f) The color of another salt of silver, AgI(*s*), is yellow. A student adds a solution of NaI to a test tube containing a small amount of solid, cream-colored AgBr. After stirring the contents of the test tube, the student observes that the solid in the test tube changes color from cream to yellow.

      (i) Write the chemical equation for the reaction that occurred in the test tube.

      (ii) Which salt has the greater value of K_{sp}: AgBr or AgI ? Justify your answer.

a. $K_{sp} = [Ag^{+1}]^1 [Br^{-1}]^1$

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1A2

b. $AgBr \rightleftharpoons Ag^{+1} + Br^{-1}$

x x x $\quad x = 7.07 \times 10^{-7}$

$5.0 \times 10^{-13} = [x][x]$

b. $[Ag^{+1}] = 7.07 \times 10^{-7}$ M

c. The value of $[Ag^{+1}]$ is equal to the value in part b. Despite the change in volume, the solid AgBr will dissociate to the same concentrations of Ag^{+1}

d. $5\text{ g } AgBr \times \frac{1\text{ mol}}{188\text{ g}} = .0266$ moles $\quad$ solubility of $AgBr = 7.07 \times 10^{-7}$

$\frac{7.07 \times 10^{-7}\text{ moles}}{1\text{ L}} = \frac{.0266\text{ moles}}{X\text{ L}}$ $\quad$ d. $X = 3.76 \times 10^{4}$ Liters

d. 3.76×10^{4} L

e. $1.5 \times 10^{-4}\text{ M} = \frac{x}{.01}$ $\quad$ $5 \times 10^{-4}\text{ M} = \frac{x}{.002}$

$x = 1.5 \times 10^{-6}$ mole Ag^{+1} $\quad$ $x = 1 \times 10^{-6}$ mole Br^{-1}

$Q_{sp} = \left[\frac{1.5 \times 10^{-6}}{.012}\right]\left[\frac{1 \times 10^{-6}}{.012}\right] = [1.25 \times 10^{-4}][8.33 \times 10^{-5}] = 1.04 \times 10^{-8}$

$Q_{sp} = 1.04 \times 10^{-8} > K_{sp} = 5. \times 10^{-13}$

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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

e. The student will observe a cream-colored precipitate forming. Because the Qsp is greater than the K_{sp}, there is enough Ag^{+1} and Br^{-1} to form a precipitate.

f i. $AgBr + I^{-1} \rightarrow AgI + Br^{-1}$

ii. AgBr has the higher K_{sp} because the I^{-1} was able to react with the AgBr. The manipulation of K values below show it.

$AgBr \rightarrow Ag^{+1} + Br^{-1}$ $\quad K_{sp}$

$Ag^{+1} + I^{-1} \leftarrow AgI$ $\quad 1/K_{sp}$

$K_{Total\ rx} > 1$ because reaction occured

$K_{sp} \cdot \frac{1}{K_{sp}} = K_{Total}$

$\frac{K_{sp}\ AgBr}{K_{sp}\ AgI} > 1$

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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

a) $K_{sp} = [Ag^+][Br^-]$ $K_{sp} = 5.0 \times 10^{-13}$ 2a&k

$AgBr \rightarrow Ag^+ + Br^-$

b) $AgBr \rightarrow Ag^+ + Br^-$

I	—	0	0
C	—	+x	+x
E	—	+x	+x

$x^2 = K_{sp} = 5.0 \times 10^{-13}$

$x = 7.1 \times 10^{-7} = [Ag^+] = [Br^-]$

$[Ag^+] = 7.1 \times 10^{-7}$

c) The concentration of $[Ag^+]$ remains the same, since the K_{sp} is independent of the amount of solvent.

d) $AgBr \leftrightarrow Ag^+ + Br^-$

$[Ag^+][Br^-] = 5.0 \times 10^{-13}$

$5.0\,g\,AgBr \times \frac{1\,mol\,AgBr}{188\,g\,AgBr} = \boxed{2.66 \times 10^{-2}}$

$2.66 \times 10^{-2}\,mol\,AgBr \times \frac{22.4\,L}{1\,mol\,AgBr}$

$= 0.596\,L$

e) $Ag^+ + NO_3^- + Na^+ + Br^- \leftrightarrow AgBr + NO_3^- + Na^+$

$Ag^+ + Br^- \leftrightarrow AgBr$

the precipitation reaction will occur since $K_{sp} = 5.0 \times 10^{-13}$

and $Q = [1.5 \times 10^{-4}][5.0 \times 10^{-4}]$, $[Ag^+] = 1.5 \times 10^{-4}$

$Q = 7.5 \times 10^{-8}$ $[Br^-] = 5.0 \times 10^{-4}$

So $K_{sp} < Q$, therefore precipitation reaction occur.

1B 2

f) ~~AgI~~ + Br

~~$Na^+ + I^- + AgBr \rightleftharpoons AgI + Na^+ + Br^-$~~

i) $I^- + AgBr \rightleftharpoons AgI + Br^-$

ii) the ksp of AgBr is bigger than that of AgI since the reaction favors the desociation of AgBr than AgI; the yellow precipitate demonstrates that the reaction favors forming AgI. Therefore AgBr has bigger ksp.

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1C.1

CHEMISTRY

Section II

(Total time—95 minutes)

Part A

Time—55 minutes

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   (b) Calculate the value of $[Ag^+]$ in 50.0 mL of a saturated solution of AgBr at 298 K.

   (c) A 50.0 mL sample of distilled water is added to the solution described in part (b), which is in a beaker with some solid AgBr at the bottom. The solution is stirred and equilibrium is reestablished. Some solid AgBr remains in the beaker. Is the value of $[Ag^+]$ greater than, less than, or equal to the value you calculated in part (b)? Justify your answer.

   (d) Calculate the minimum volume of distilled water, in liters, necessary to completely dissolve a 5.0 g sample of AgBr(*s*) at 298 K. (The molar mass of AgBr is 188 g mol^{-1}.)

   (e) A student mixes 10.0 mL of 1.5×10^{-4} *M* $AgNO_3$ with 2.0 mL of 5.0×10^{-4} *M* NaBr and stirs the resulting mixture. What will the student observe? Justify your answer with calculations.

   (f) The color of another salt of silver, AgI(*s*), is yellow. A student adds a solution of NaI to a test tube containing a small amount of solid, cream-colored AgBr. After stirring the contents of the test tube, the student observes that the solid in the test tube changes color from cream to yellow.

      (i) Write the chemical equation for the reaction that occurred in the test tube.

      (ii) Which salt has the greater value of K_{sp}: AgBr or AgI? Justify your answer.

a) $K_{sp} = [Ag^+][Br^-]$

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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

b) $AgBr_{(s)} \rightarrow Ag^+ + Br^-$ $\quad K_{sp} = [Ag^+][Br^-]$

I	0	0	$= (x)(x)$
C	+x	+x	$5.0 \times 10^{-13} = x^2$
E	x	x	$x = 7.07 \times 10^{-7} M [Ag^+]$

c) the value of $[Ag^+]$ will not change, because it is a saturated solution, it already reacts as much as it can so no matter how many water add in, it will not change the $[Ag^+]$.

d) $2AgBr + H_2O \Rightarrow 2HBr + Ag_2O$

$5.0\,g \times \frac{1\,mol}{188\,g} = 2.65 \times 10^{-2}\,mol\ AgBr$ $\quad 2.65 \times 10^{-2} \div 2 = 0.0133\,mol\ H_2O$

$2.65 \times 10^{-2}\,mol \div 0.05\,L = 0.53\,M$ of $AgBr$

$0.53\,M \times \frac{1\,H_2O}{2\,AgBr} = 0.27\,M\ H_2O$

$0.0133 \div 0.27 = 4.93 \times 10^{-2}\,L\ H_2O$

e) $AgNO_3 + NaBr \rightarrow AgBr + NaNO_3$

the student will get cream-colored silver salt, because $NaNO_3$ is soluable, $AgBr$ will form a solid precipitate

f) i: $NaI + AgBr \rightarrow AgI + NaBr$

ii: AgI will has the greater value of K_{sp} because I^- is a bigger molecule than Br, which has more electron repulsion than Br has with Ag. it is easier to break the bonds between AgI instead of $AgBr$.

AP® CHEMISTRY
2010 SCORING COMMENTARY

Question 1

Overview

This question assessed the students' knowledge and skills concerning the concept of the equilibria that exist with slightly soluble salts. Parts of the question were mathematical and parts were conceptual in nature. In parts (a) and (b) students were required to write the correct K_{sp} expression of AgBr and then calculate the $[Ag^+]$ using the K_{sp} provided. In part (c) students had to recognize that the $[Ag^+]$ remains constant in a saturated solution after the addition of water when solid AgBr remains after equilibrium is reestablished. Part (d) required students to calculate the minimum volume of water necessary to completely dissolve 5.0 grams of AgBr. Students had to convert grams to moles and then divide this answer by the molarity of the silver ion calculated in part (b). In part (e) students were expected to recognize that a precipitate of AgBr would occur. First, students had to calculate the concentration of Ag^+ and Br^- ions present when $AgNO_3$ and NaBr solutions were mixed, solve for Q, and, finally, compare the Q value to the given K_{sp}. Part (f)(i) required students to write a balanced chemical equation that represents the formation of silver iodide when an aqueous solution of sodium iodide is mixed with solid silver bromide. Part (f)(ii) asked students to draw the conclusion that AgBr had a greater K_{sp} than AgI based on the laboratory evidence given.

Sample: 1A
Score: 10

This response earned all 10 points: 1 point for part (a), 1 point for part (b), 1 point for part (c), 2 points for part (d), 3 points for part (e), 1 point for part (f)(i), and 1 point for part (f)(ii).

Sample: 1B
Score: 8

In part (d) this response earned the first point for calculating moles of AgBr but did not earn the second point for volume. In part (e) the response did not earn the point for calculating the concentration of the $[Ag^+]$ and $[Br^-]$ ions in solution. The response earned the other 2 possible points for the Q vs. K_{sp} argument with the appropriate conclusion.

Sample: 1C
Score: 6

In part (d) this response earned the first point for calculating moles of AgBr but did not earn the second point for volume. In part (e) the response earned 1 point for recognizing that a AgBr precipitate would form. In part (f)(ii) the response did not earn the point when AgI was chosen to have the higher K_{sp}.